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FORTRAN PROGRAM FOR WEIBULL PARAMETER ESTIMATION

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FORTRAN PROGRAM FOR WEIBULL PARAMETER ESTIMATION

by

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ABSTRACT

The Weibull distribution has been widely used as its three parameters generate a complete family of curves which will approximate nearly any probability distribution function. This report provides FORTRAN program listings for estimating the Weibull distribution for both complete and censored samples. The first program "WEIBULL" inputs data through a file the first line of which is a format line., describing how the data are structured in the file. The second program, "PEWEIBULL" produces plots of the probability density function (p.d.p.) and accumulative density function (c.d.f.) from the output data from "WEIBULL" (the Weibull parameters). The examples of an input file and two graphs produced are included.

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CALCUL DES PARAMÈTRES DE WEIBULL À L'AIDE D'UN PROGRAMME FORTRAN

par

J.K. Szymanski*, V. Srajer**, N.J. Stuart***, et R. Kolada****

RÉSUMÉ

L'emploi de la fonction de distribution de Weibull est très répandu puisque ses trois paramètres produisent une famille complète de courbes, qui se rapprochera de presque toutes les fonctions de distribution des probabilités. Le présent rapport donne une liste d'un programme FORTRAN permettant d'estimer la distribution de Weibull pour les échantillons complets ou partiels. Le premier programme "WEIBULL" entre des données au moyen d'un fichier dont la première ligne est une ligne de disposition des données décrivant comment les données sont structurées dans le fichier. Le deuxième programme "PEWEIBULL" produit des courbes de la fonction de distribution des probabilités et de la fonction de densité accumulée à partir des données de sortie du "WEIBULL" (les paramètres de Weibull). Enfin, deux exemples du fichier d'entrée et deux illustrations des diagrammes obtenus sont aussi présentés.

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INTRODUCTION

The Operations Research group of CANMET's Surface Mining Laboratory is involved with gathering much time study data on equipment such as draglines, trucks and coaling machines. Increasingly the field data acquisition is being computerized and the production of the basic statistics, such as time/frequency histograms, is being automated. This data is of direct interest to the operators who greatly welcome objective, independent information on their equipment performance.

The ultimate aim, however, to understand the performance of these machines in a non-site specific way. An important tool in this endeavour is the statistical model - a model that allows for randomized components to simulate the interaction and performance of equipment under different configurations. Though some models can accept histogram data directly it is generally more desirable to fit a statistical distribution function to the experimental data. This fitting process, however, close the fit, is an interpretation of the data. Various curves may be fitted - lognormal, poison's etc. Under certain circumstances there may be theoretical reasons for the selection of a given choice. In the absence of this the Weibull distribution is a very flexible distribution, its three parameters generate a family of curves which will approximate nearly any probability distribution (1,2,3).

A simple Weibull cumulative distribution function (c.d.f.) may be defined mathematically as follows:

$$F(t) = 1 \exp\left(-(t-t_o)/\eta^{\beta}\right) \text{ for } t > 0 \qquad (1)$$

$F(t)$	-	fraction of times less than a given value,
t	-	cycle time,
t_o	-	starting point or origin of the distribution,
η	-	characteristic of life or scale parameter,
β	-	slope or shape parameter, and
exp	-	exponential

The most important parameter, β, gives the distribution its many shapes, as shown in Figure 1. For $\beta = 1$, the distribution is exponential; for $\beta = 3.6$, it very closely approximates a normal distribution. At about $\beta = 1.5$, the distribution is nearly log-normal.

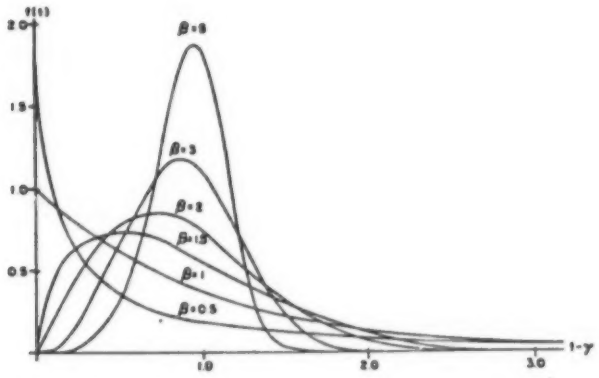

Figure 1 The Weibull density function for shape parameter β with $\alpha = 1.0$.

This report describes a FORTRAN program listing for estimating the Weibull distribution of both complete and censored samples. The program will estimate the parameters of a Weibull distribution by the rank regression and maximum likelihood technique.

WEIBULL PARAMETER ESTIMATION COMPUTER PROGRAMS

Two programs are provided in FORTRAN 77 (using "calComp" graphics software for PEWEIBULL). The programs run in the immediate mode, i.e., the user is prompted for input with no printout options. If a histogram of the population is available, along with the times interval of interest, a Weibull analysis can be produced. The histogram is input bar by bar and the program assigns the midpoint time of each bar to all of the units in the bar.

The listings on Figures 2 and 3 provide the details of the programs design.

Both programs are found in [JOZEF.MODEL] directory.

The WEIBULL program inputs data through an input file that contains a format line in the first line of the file. This format line describes how the data is formatted in the file. This is useful when data file contains many columns and you can only use one column. For example, if you have five columns in the format (5f5.3), you can use the third column of data by using the format statement (10x, f5.3).

The program is executed by: Run WEIBULL.

- You are asked to input the name of the data file.
- The program will calculate BETA, ETA, R, and R squared.
- The program will also estimate max. likelihood if desired.

If you are on terminal connected to the "colComp" plotter, the execution is: Run PWEIBULL.

- You are asked to input BETA, ETA, and R squared.
- You are asked to input the maximum time. This number should be larger than the largest data value in the file used in WEIBULL.
- You will enter the graph name.
- The program will plot two graphs (C.D.F. and P.D.F.).
  The formula used to calculate C.D.F. is:

```
F(T)=1.-EXP(-TETA)**(BETA)                                    (2)
```

  The formula used to calculate P.D.F. is:

```
F(T)=(BETA/ETA)*((T/ETA)**(BETA-1.))*EXP(-T/ETA)**BETA)       (3)
```

- You will be required to relocate the plotter onto a second page as each graph takes a full page. Once you have relocated the plotter, press <RETURN> key to start the second graph

Figures 4 and 5 show the output plots of probability density and cumulative Weibull distribution function when this program is run with a set of input values characteristic of an "Easi-Miner" and trucks operation (Figure 6).

```
      COMMON /BLOCK1/INT,TIME,MM,IHIST
      DIMENSION IS(100),RANKMD(100),A(100),ORDER(100)
      DIMENSION YX(100),INT(100),TIME(100),V(100)
      DIMENSION IZ(100),X(100),Z(7)
      CHARACTER FNAME*40,FMT*12
      DATA ANO/'N'/,PERINT/50./
      IPRNT=1
      IPOP=0
      ISUM=0
701   WRITE(*,2000)
2000  FORMAT(2X,'INPUT THE FILE NAME')
      READ(*,1998) FNAME
1998  FORMAT(A40)
      OPEN(UNIT=1,FILE=FNAME,STATUS='OLD')
      READ(1,'(A12)') FMT
      I=0
1     I=I+1
      READ(1,FMT,END=2) A(I)
      IF(A(I).EQ.0.0) GOTO 3
      GOTO 1
3     I=I-1
      GOTO 1
2     N=I-1
      BN=N+ISUM
      DO 4 J=1,N
4     V(J)=ABS(A(J))
      CALL ORD(V,N,IZ)
      DO 22 I=1,N
      ISUB=IZ(I)
22    X(I)=A(ISUB)
      DO 23 I=1,N
23    A(I)=X(I)
      BN1=BN+1
      DJ=1.0
      BJ=0.0
      M=0
      SUMX=0.0
      SUMY=0.0
      SUMXX=0.0
      SUMYY=0.0
      SUMXY=0.0
      WRITE(*,990)
990   FORMAT(2X,'PT.',4X,'DATA',4X,'ORDER',4X,'MEDIAN RANK')
      DO 630 K=1,N
      ISUM=0
      IF(IPOP.EQ.0) GOTO 632
      DO 631 J=1,MM
      IF(TIME(J).LT.A(K)) ISUM=ISUM+INT(J)
631   CONTINUE
      IS(K)=ISUM
632   BK=ISUM+K
      IF(IPOP.EQ.1) BK=BK-1.0
      IF(IPOP.EQ.1.AND.K.EQ.1) DJ=(BN1-BJ)/(BN1-BK)
      IF(K.EQ.1) GOTO 3911
      IF(IPOP.EQ.0) GOTO 3911
3901  DJ=(BN1-BJ)/(BN1-BK)
3911  IF(A(K))390,900,400
390   DJ=(BN1-BJ)/(BN1-BK)
      GOTO 630
400   BJ=BJ+DJ
      ORDER(K)=BJ
      RANKMD(K)=(ORDER(K)-.3)/(BN+.4)
      XXX=ALOG(A(K))
      YPRIME=1./(1.-RANKMD(K))
      Y=ALOG(ALOG(YPRIME))
      YX(K)=Y
```

Figure 2 - Fortran program design for a calculation of Weibull parameters.

```
      WRITE(*,300) K,A(K),ORDER(K),RANKMD(K)
300   FORMAT(I6,F10.1,F10.4,F12.5)
      M=M+1
      SUMX=SUMX+XXX
      SUMXX=SUMXX+XXX*XXX
      SUMY=SUMY+Y
      SUMYY=SUMYY+Y*Y
      SUMXY=SUMXY+XXX*Y
630   CONTINUE
      WRITE(*,800)SUMX,SUMY,SUMXX,SUMYY,SUMXY
800   FORMAT(2X,'SUMX=',E20.7,'SUMY=',E20.7,/,2X,
     3       'SUMXX=',E20.7,'SUMYY=',E20.7,'SUMXY=',E20.7)
      GM=M
      BETA=(GM*SUMYY-SUMY*SUMY)/(GM*SUMXY-SUMX*SUMY)
      ALPLN=(BETA*SUMX-SUMY)/GM
      AVED=ALPLN/BETA
      ETA=EXP(AVED)
      WRITE(*,3101)
3101  FORMAT(2X,'THE FOLLOWING ESTIMATES ARE RANKED REGRESSION ',
     3       'ESTIMATES')
      WRITE(*,3100) BETA,ETA
3100  FORMAT(/,2X,'BETA=',F10.4,' ETA=',F20.7)
      R=0.0
      IF((SUMXX-SUMX*SUMX/GM).LT.0.0) GOTO 7871
      XNUM=SUMXY-SUMX*SUMY/GM
      DENOM=SQRT((SUMXX-SUMX*SUMX/GM)*(SUMYY-SUMY*SUMY/GM))
      R=XNUM/DENOM
      IF(R.GT.1.0) R=1.0
7871  RSQ=R*R
      WRITE(*,3200) R,RSQ
3200  FORMAT(2X,'R=',F10.5,'R**2=',F10.5)
      WRITE(*,5001)
5001  FORMAT(2X,'DO YOU WISH TO DO MAXIMUM LIKELIHOOD ESTIMATION?',
     3       /,2X,'ANSWER Y OR N')
      READ(*,'(A1)') ANS
      IF(ANS.EQ.ANO) GOTO 900
      IHIST=IPOP
      CALL MAXL(A,N,IPRNT,BML,TML,BETA)
900   CONTINUE
      STOP
      END

      SUBROUTINE ORD(A,N,IZ)
      DIMENSION A(1),IZ(1)
      DO 1 J=1,N
1     IZ(J)=J
      IF(N.EQ.1) RETURN
      NM=N-1
      DO 2 K=1,N
      DO 2 J=1,NM
      N1=IZ(J)
      N2=IZ(J+1)
      IF(A(N1).LT.A(N2)) GOTO 2
      IZ(J+1)=N1
      IZ(J)=N2
2     CONTINUE
      RETURN
      END

      SUBROUTINE MAXL(T,NUM,IPRNT,BML,TML,BETA)
      DIMENSION TT(100),T(1),XX(100),INT(100),TIME(100)
      COMMON /BLOCK/TT,NSAMP
      COMMON /BLOCK1/INT,TIME,MM,IHIST
      COMMON /BLOCK2/XX,NFAIL
      IH=IHIST
      NSAMP=NUM
```

```
      NFAIL=0
      DO 1 I=1,NSAMP
      TT(I)=ABS(T(I))
      IF(T(I).LT.0.0D0) GOTO 1
      NFAIL=NFAIL+1
      XX(NFAIL)=T(I)
1     CONTINUE
      TOL=.000001
      NLIM=100
      X=BETA
      PB=0.001
      NCT=0
      DELX=.001
      DELY=.01
30    PRN=AUX(X)
      IF(IPRNT.EQ.1) WRITE(*,206) X,PRN
206   FORMAT(2X,'BETA=',E15.5,' LN MAXLIKELIHOOD=',E20.7)
      CALL SLOPE(X,Pb,PRN,DELX,DELY,TOL,ISIG,NCT,NLIM,1)
      GOTO (30,50,40,50),ISIG
      GOTO 30
40    IF(IPRNT.EQ.1) WRITE(*,205) FPR,PB,PRN
205   FORMAT(2X,'ITERATION FAILURE ',3E20.7)
      IFLAG=1
      RETURN
50    BML=X
      SUM=0.0D0
      RN=NFAIL
      DO 110 I=1,NUM
110   SUM=SUM+TT(I)**BML
      IF(IHIST.EQ.0) GOTO 112
      DO 111 I=1,MM
111   SUM=SUM+FLOAT(INT(I))*TIME(I)**BML
112   SUM=SUM/RN
      TML=SUM**(1./BML)
      WRITE(*,996)
996   FORMAT(2X,'MAXIMUM LIKELIHOOD ESTIMATES FOR THIS CASE FOLLOW')
      WRITE(*,995) BML,TML
995   FORMAT(2X,'BETA=',F10.3,' ETA=',F20.2)
      RETURN
      END

      FUNCTION AUX(X)
      DIMENSION T(100),XX(100),INT(100),TIME(100)
      COMMON /BLOCK/T,N
      COMMON /BLOCK1/INT,TIME,MM,IHIST
      COMMON /BLOCK2/XX,NFAIL
      ZZZ=NFAIL
      SUM1=0.
      SUM2=0.
      SUM3=0.
      IF(ABS(X).GT.15.0.OR.X.LE.0.0) X=0.1
      DO 10 I=1,N
      SUM1=SUM1+T(I)**X
10    SUM2=SUM2+ALOG(T(I))*T(I)**X
      IF(IHIST.EQ.0) GOTO 11
      DO 20 I=1,MM
      SUM1=SUM1+FLOAT(INT(I))*TIME(I)**X
20    SUM2=SUM2+FLOAT(INT(I))*ALOG(TIME(I))*TIME(I)**X
11    DO 15 I=1,NFAIL
15    SUM3=SUM3+ALOG(XX(I))
      AUX=SUM2/SUM1-SUM3/ZZZ-1.0/X
      RETURN
      END

      SUBROUTINE SLOPE(X,YA,YB,X1,DEL1,TOL,JK,NCT,NTIME,LOOP)
      JK=1
```

```
      IF((ABS((YA-YB)/YA))-TOL)6,6,3
3     IF(NCT-1)1,1,2
1     X1=X
      DEL1=YA-YB
      NCT=NCT+1
      X=X*1.02
      GOTO 9
2     IF(NCT-NTIME)5,5,4
5     X2=X
      DEL2=YA-YB
      IF(ABS(DEL2-DEL1).LT.1.E-06) GOTO 20
      X=X2-DEL2*(X2-X1)/(DEL2-DEL1)
      IF(X)8,8,10
10    IF(X-X2)11,7,12
11    IF((X/X2)-.6)13,13,8
13    X=X2*.75
      GOTO 8
12    IF((X/X2)-1.4)8,14,14
14    X=X2*1.25
      GOTO 8
7     X=X2*1.02
8     X1=X2
      DEL1=DEL2
      NCT=NCT+1
      GOTO9
6     JK=2
      NCT=2
      GOTO 9
4     WRITE(*,100) LOOP,X,YA,YB
100   FORMAT(1H0,'CONVERGENCE FAILURE IN LOOP',I2/1H,'X=',E14.8,4X,'YA=',
     3       E14.8,4X,'YB=',E14.8,/)
      JK=3
      NCT=1
9     CONTINUE
      RETURN
20    JK=4
      RETURN
      END
```

```
      PROGRAM PWEIBULL
C     LINK PWEIBULL+GRAPHICS
      REAL BETA,ETA,P(1000),Q(1000),Z,J,INC,IMAX,RSQU
      INTEGER N
      CHARACTER FNAME*50,TITLE*50

c     Input parameters.

      WRITE(*,*) 'INPUT BETA, ETA, AND R**2:'
      READ(*,*) BETA,ETA,RSQU

      WRITE(*,*) 'INPUT MAXIMUM TIME:'
      READ(*,*) IMAX

      WRITE(*,*) 'INPUT GRAPH NAME:'
      READ(*,'(A50)') FNAME
      CALL CHARCOUNT(FNAME,N)

c     Weibull C.D.F. plotting.

      TITLE='Fig.  - WEIBULL C.D.F. for '//FNAME(1:N)
      CALL CHARCOUNT(TITLE,N)

      INC=IMAX/500.

      I=0
      Z=0.0

c     Calculation of f(t).

      DO 100 J=0.000001,IMAX,INC
            I=I+1
            P(I)=1.-EXP(-(J/ETA)**BETA)
            Q(I)=J
            IF(Z.LT.P(I)) Z=P(I)
100   CONTINUE

c     Start plotting graph.

      CALL PLOTS(0,0,6)
      CALL PLOT(6.,6.,-3)

      CALL AXIS(0.,0.,'Time (min)',-10,10.,0.,0.,IMAX/10.)
      CALL AXIS(0.,0.,'F(t)',4,10.,90.,0.,Z/10.)
      CALL PLOT(0.,10.,3)
      CALL PLOT(10.,10.,2)
      CALL PLOT(10.,0.,2)

      P(501)=0.
      P(502)=Z/10.
      Q(501)=0.
      Q(502)=IMAX/10.
      CALL LINE(Q,P,500,1,0,0)
      CALL SYMBOL(0.,-2.,.3,TITLE(1:N),14,0.0,N)
      CALL SYMBOL(11.,4.,.2,'BETA=',14,0.0,5)
      CALL NUMBER(12.2,4.,.2,BETA,0.0,2)
      CALL SYMBOL(11.,3.3,.2,'ETA =',14,0.0,5)
      CALL NUMBER(12.2,3.3,.2,ETA,0.0,2)
      CALL SYMBOL(11.,2.6,.2,'R**2=',14,0.0,5)
      CALL NUMBER(12.2,2.6,.2,RSQU,0.0,2)

      CALL PLOT(0.,0.,999)

c     Prompt for next graph and relocate plotter pen on new paper.

      WRITE(*,*) ' RELOCATE PLOT WITH NEW PAPER'
```

Figure 3 - Fortran program design for producing plots of p.d.f. and c.d.f. of Weibull distribution using the calcomp electromechanical plotter.

```
      WRITE(*,*) ' PRESS RETURN WHEN READY'
      ACCEPT *

c     Weibull P.D.F. plotting.

      TITLE='Fig.  - WEIBULL P.D.F. for '//FNAME(1:N)
      CALL CHARCOUNT(TITLE,N)

      INC=IMAX/500.

      I=0
      Z=0.0

c     Calculation of f(t).

      DO 200 J=0.00001,IMAX,INC
         I=I+1
         P(I)=(BETA/ETA)*((J/ETA)**(BETA-1.))*EXP(-(J/ETA)**BETA)
         Q(I)=J
         IF(Z.LT.P(I)) Z=P(I)
200   CONTINUE

c     Start plotting graph.

      CALL PLOTS(0,0,6)
      CALL PLOT(6.,6.,-3)

      CALL AXIS(0.,0.,'Time (min)',-10,10.,0.,0.,IMAX/10.)
      CALL AXIS(0.,0.,'F(t)',4,10.,90.,0.,Z/9.)
      CALL PLOT(0.,10.,3)
      CALL PLOT(10.,10.,2)
      CALL PLOT(10.,0.,2)

      P(501)=0.
      P(502)=Z/9.
      Q(501)=0.
      Q(502)=IMAX/10.
      CALL LINE(Q,P,500,1,0,0)
      CALL SYMBOL(0.,-2.,.3,TITLE(1:N),14,0.0,N)
      CALL SYMBOL(11.,4.,.2,'BETA=',14,0.0,5)
      CALL NUMBER(12.2,4.,.2,BETA,0.0,2)
      CALL SYMBOL(11.,3.3,.2,'ETA =',14,0.0,5)
      CALL NUMBER(12.2,3.3,.2,ETA,0.0,2)
      CALL SYMBOL(11.,2.6,.2,'R**2=',14,0.0,5)
      CALL NUMBER(12.2,2.6,.2,RSQU,0.0,2)

      CALL PLOT(0.,0.,999)

      END

*******************************

      SUBROUTINE CHARCOUNT(TEXT,N)

      INTEGER I,N
      CHARACTER TEXT

      DO 100 I=1,50
            IF(TEXT(I:I).NE.' ') N=I
100   CONTINUE

      RETURN
      END
```

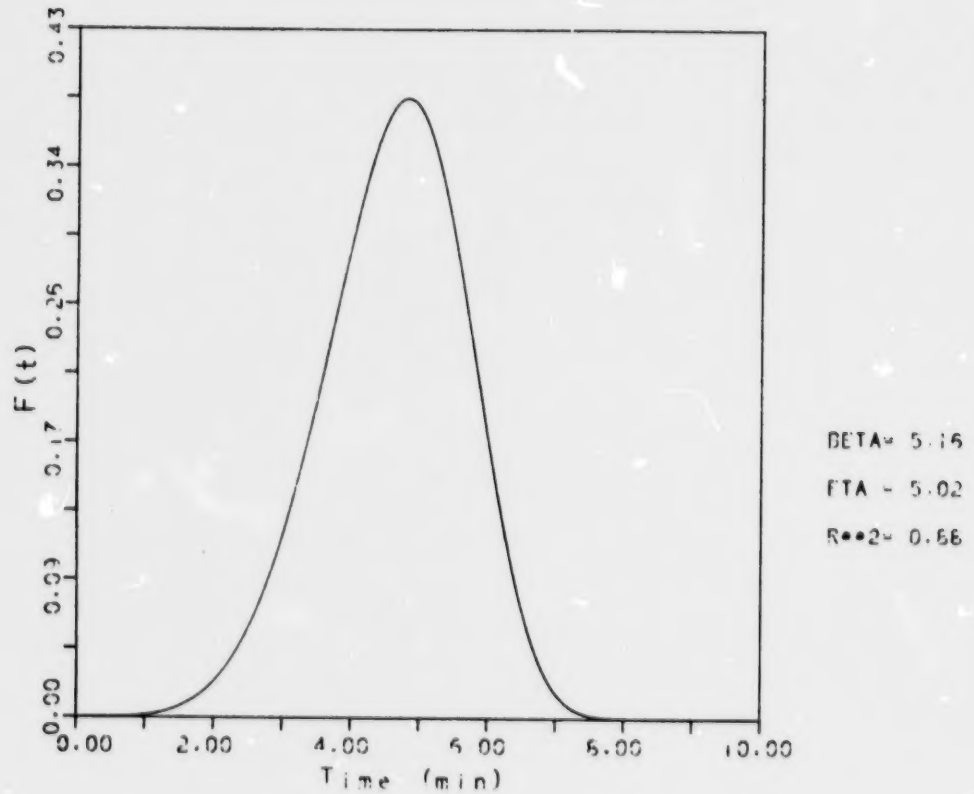

Fig. 4 - WEIBULL P.D.F. for SAMPLE OUTPUT

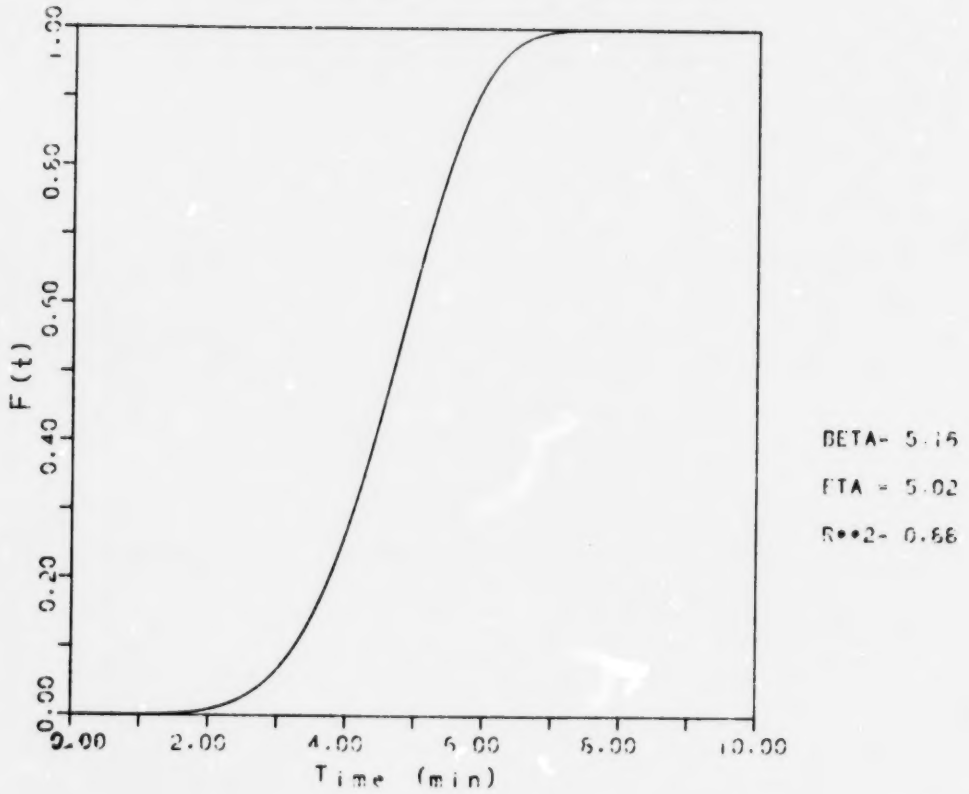

Fig. 5 - WEIBULL C.D.F. for SAMPLE OUTPUT

Format line (this one reads the last column)

(24X,F8.2)

```
1307.00    4.33    0.17    2.72
1304.00    2.10    1.03    3.50
1301.00    0.00    0.00    5.08
1307.00    1.33    0.67    3.52
1304.00    6.50    0.17    3.08
1301.00    1.33    0.42    3.25
1307.00    0.00    0.00    4.73
1304.00    1.17    0.17    5.00
1301.00    6.17    0.17    3.33
1307.00    7.67    0.25    5.00
1301.00    0.00    0.00    7.42
1307.00    3.00    0.25    2.92
1304.00    4.67    0.58    4.58
1301.00    0.00    0.00    5.08
1307.00    7.92    0.53    3.92
1304.00   11.70    0.30    3.33
1301.00    0.83    0.17    5.17
1307.00    0.00    0.00    4.07
1304.00    2.87    0.83    3.92
1301.00    3.42    0.30    3.70
1307.00    0.50    0.25    4.17
1304.00    0.00    0.00    5.00
1301.00    2.83    0.92    5.08
1307.00    4.83    0.33    3.42
1304.00    0.25    0.42    3.50
1301.00    0.00    0.00    4.63
1307.00    2.50    1.67    4.75
1301.00    2.25    0.58    4.25
1304.00    5.33    0.33    5.33
1307.00    5.00    0.30    3.87
1301.00    3.83    0.75    4.25
1304.00    0.17    0.25    4.42
1301.00    0.00    0.00    4.92
1307.00    3.42    0.25    3.00
1304.00    3.33    1.00    4.08
1301.00    0.00    0.00    4.17
1307.00    0.00    0.00    3.92
1304.00    0.00    0.00    4.58
1301.00    5.67    0.50    2.83
1307.00    4.50    0.33    3.50
1304.00    0.00    0.00    7.58
1301.00    8.50    1.17    3.50
1307.00    0.00    0.00    6.27
1304.00    8.00    0.50    5.50
1301.00    6.33    0.25    4.42
1307.00    4.17    0.33    5.67
1304.00    3.83    0.33    5.97
1301.00    6.30    0.70    4.17
1307.00    3.33    0.25    4.50
1301.00    0.00    0.00    4.13
1304.00    4.83    0.17    5.57
1307.00    0.00    0.00    6.58
1304.00    0.00    0.00    3.98
1301.00    1.55    1.13    3.75
1307.00    0.43    0.15    3.20
1304.00    0.00    0.00    3.62
1301.00    2.07    0.28    5.27
1307.00    1.58    0.18    4.85
1304.00    0.53    0.23    3.48
1301.00    0.00    0.00    3.48
1307.00    0.00    0.00    3.77
1304.00    2.47    1.27    2.88
1301.00    2.05    0.38    3.73
1304.00    0.00    0.00    4.13
1301.00    0.00    0.00    3.63

1307.00    0.00    0.00    3.38
1301.00    0.00    0.00    3.83
1304.00    0.00    0.00    3.88
1307.00    0.93    1.10    6.18
1301.00    5.05    0.30    4.00
1304.00    0.00    0.00    4.62
1307.00    0.00    0.00    4.28
1304.00    0.00    0.00    4.43
1307.00    0.00    0.00    4.07
1301.00    4.58    0.40    8.17
1304.00    0.00    0.00    3.82
1307.00    3.07    0.27    4.53
1301.00    2.17    0.40    5.27
1304.00    2.05    0.48    3.88
1307.00    0.00    0.00    5.02
1301.00    0.77    0.23    6.58
1304.00    0.58    0.58    5.98
1307.00    2.57    0.27    5.58
1301.00    6.08    0.25    6.23
1304.00    4.40    0.27    9.42
1307.00    8.58    0.33    4.43
1301.00    7.35    0.22    4.15
1304.00    0.00    0.00    5.57
1307.00    1.53    0.30    4.83
1301.00    0.00    0.00    6.32
1304.00    1.92    1.08    5.00
1307.00    0.58    0.33    8.00
1301.00    1.50    0.35    6.88
1304.00    4.32    0.25    4.10
1307.00    0.00    0.00    6.92
1301.00    0.17    0.65    5.43
```

Figure 6 - The TEST.DAT file for Weibull plots.

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REFERENCES

1. Abernethy, R.B., Breneman, J.E., Medlin, G.LO., "Weibull analysis handbook". Acro Propukion Laboratory Air Force Wright Aeronautical Laboratories Air Force Systems Command, United States Air Force, Wright-Patterson AFB, Ohio 45433, November, 1983.

2. Dumonceaux, R., Antile, CH., "Discrimination between the Log-Normal and the Weibull distributions". Technometrics, Vol. 15, No. 4, November, 1973.

3. Weibull, W., "A statistical distribution function of wide applicability". Journal of Applied Mechanics, September, 1951.